Development of the Calculation Module for Uncertainty of Internal Dose Coefficients

Siwan Noh [a], Tae-Eun Kwon [a], Mee-Ryeong Kim [a], Jai-Ki Lee [a*], Han-Ki Jang [b], Tai Jin Park [b]
[a]*Dept. of Nuclear Engineering,, Hanyang Univ., 222 Wangsimni-ro, Seongdong-gu, Seoul 133-791*
[b]*Korean Association for Radiation Application, 77, Seongsuil-ro, Seongdong-gu, Seoul 133-822*
[*]*Corresponding author: jakilee@hanyang.ac.kr*

1. Introduction

Internal Dose Coefficients mean the committed tissue equivalent or effective dose per unit intake, which is one of the most important factor for internal dosimetry. In general, the internal dose coefficients have been published from the ICRP (International Commission on Radiological Protection) for inhalation and ingestion of radioactive materials. Although the ICRP provides the coefficients as point values without uncertainties, it is important to understand sources of uncertainty in the derivation of the coefficients [1].

When internal dose coefficients are calculated, numerous factors are involved such as transfer rate in biokinetic models, absorption rates and deposition in respiratory tract model, fractional absorption in alimentary tract model, absorbed fractions (AF), nuclide information and organ mass. These factors have uncertainty respectively, which increases the uncertainty of internal dose coefficients by uncertainty propagation. Since the procedure of internal dose coefficients calculation is somewhat complicated, it is difficult to propagate the each uncertainty analytically. Therefore, the calculation module for uncertainty of internal dose coefficients is needed using non-analytical method.

In this study, we developed the calculation module for uncertainty of internal dose coefficients using the Monte Carlo method that is widely used for uncertainty propagation. Also, the internal dose coefficient for inhalation of ^{90}Sr with uncertainty was calculated using the developed module. The development of module and calculation were performed by MATLAB.

2. Methods and Results

2.1 Development of the uncertainty calculation module

The procedure of internal dose coefficients calculation is largely divided into two parts, U(50) (The number of disintegration for 50 years at each compartment) and SEE (Specific Effective Energy) calculation like Fig. 1.

The U_{50} is calculated using biokinetic compartment models in which each organs are considered as independent compartment and material transfer between compartments is described by transfer rates, λ (d^{-1}). Using the compartment model, U(50) can be calculated as following equation [2]:

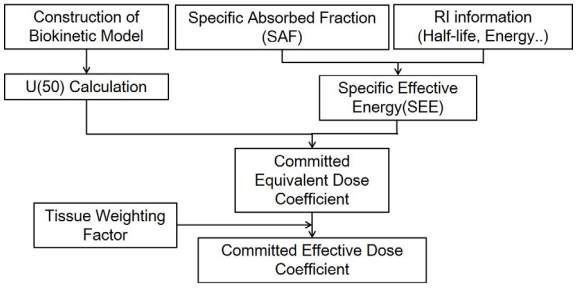

Fig. 1. The general procedure for calculation of the internal dose coefficient (committed effective dose coefficient).

$$U(50) = \lambda[A]^{-1}(e^{[A]50yr} - [I])q_0 \quad (1)$$

where λ is decay constant if q_0 is given in the number of atoms or 8.64×10^4 for the number of transformations, $d^{-1}Bq^{-1}$ if q_0 is given in Bq, [A] is the transfer rate matrix composed by transfer rates between compartments, [I] is identity matrix, and is the initial vector that contains the initial activities in each compartment. In this equation, each factor has uncertainties, which results in the uncertainty of U(50) by the uncertainty propagation. Since this equation is solved using matrix calculation, however, it is difficult to propagate uncertainty analytically. Thus, we used the Monte Carlo method in which the factors necessary for the U(50) are sampled from probabilistic distribution for each factor.

In the Monte Carlo method, sampling method is very important. Most widely used sampling methods in the Monte Carlo method are as follow: direct inversion of cumulative density function (cdf), numerical inversion of cdf, probability mixing method and rejection method. Among these methods, we used the rejection method because the method has very simple algorithm and can be applied regardless if probability density function (pdf) is integrable or not. Using this method, the developed module samples relevant factors as shown in Table 1.

Another necessary value, SEE in target organ (T) from source organ (S) for radiation type (R) is calculated as following equation:

$$SEE(T \leftarrow S)_R = \frac{AF(T \leftarrow S)_R}{M_T} y_R E_R w_R \quad (2)$$

where AF is absorbed fraction in target organ from source organ, M is mass of target organ, y_R is emission

Table I: Sampled factors related to the U(50) calculation.

Biokinetic model	Factor
Respiratory tract model	Deposition fraction, Clearance rate, Absorption rate
Alimentary tract model	Transfer rate, Fractional absorption (f_1)
Systemic model	Transfer rate (or biological half-life and fractional transfer)

yield, E_R is radiation energy, and w_R is radiation weighting factor.

Among these factors, we only considered uncertainty of M_T because uncertainty of nuclear data such as y_R and E_R is relatively very low compared to that of other factors and w_R does not have uncertainty. Even though AF has uncertainty, we did not considered the uncertainty of AF in this development because information on the uncertainty is rarely available now, thus will be considered later. When calculating the uncertainty of SEE, the Monte Carlo method with the rejection sampling method is used in the same way.

After uncertainties of factors for U(50) and SEE are all sampled, U(50) and SEE are calculated using equation (1) and (2). By multiplying the U(50) and SEE, we can get committed equivalent dose for each organ and finally get committed effective dose (internal dose coefficient) by tissue weighting factor (w_T). Since this coefficient is just a single value from a singular Monte Carlo sampling, it is indispensable to repeat until the result becomes statistically significant; below 5 % of relative error in this study. After this repetition, we can obtain the distribution and percentile values of the internal dose coefficient. In this study, MATLAB 2014a was used to develop the uncertainty calculation module.

2.2 Application of the module to inhalation of ^{90}Sr

In order to test the developed module, we calculated the internal dose coefficient for inhalation of ^{90}Sr with uncertainty using the module. The reason why we selected ^{90}Sr as the test nuclide is that there are relatively enough uncertainty data for the calculation. In this test, applied models are as shown in Table II.

For the clearance model of the ICRP publication 66 [3] respiratory tract model, clearance rate has log-normal distribution with factor of 3 uncertainty, but rapid clearance from BB and bb compartments has factor of 1.5 and 2 respectively [4]. In the case of absorption rate, strontium specific data with distribution [5] was selected instead of three absorption type (F, M, S) in ICRP publication 66 because the absorption rate for three type is not based on enough experiment data and thus has not uncertainty data. In the case of alimentary tract model, HATM (Human Alimentary Tract Model) from ICRP publication 100 [6] was used instead of ICRP publication 30 [7] model because there

Table II: Applied models and factors for uncertainty test calculation of inhalation of ^{90}Sr.

Respiratory tract model	Clearance model: ICRP 66 [3] Absorption rate: *M. Puncher* [5]
Alimentary tract model	Biokinetic model: ICRP 100 [6] f_1: NCRP 164 [8]
Systemic model	Biokinetic model: ICRP 67 [9]
Specific absorbed fraction	Absorbed fraction: MIRD phantom based AF Organ mass: *A. I. Apostoaei et. al* [10]

are not uncertainty data for the ICRP publication 30 model. Fractional absorption (f_1) distribution for strontium was selected from NCRP publication 164 [8]. The systemic model for strontium was chosen from ICRP publication 67 [9] and distribution for transfer rates of the model was provided from NCRP publication 164 [8]. In the test calculation, uncertainty of organ masses was also considered and the distribution from previous study [10] was used.

Using the developed module and selected factors, we obtained the distribution of the internal dose coefficient for inhalation of ^{90}Sr. The calculation was repeated 400 times and relative error of the result was below 5 %. The distribution of the coefficient is as shown in Fig. 2 and 5, 50, 95 percentile values are shown in Table III.

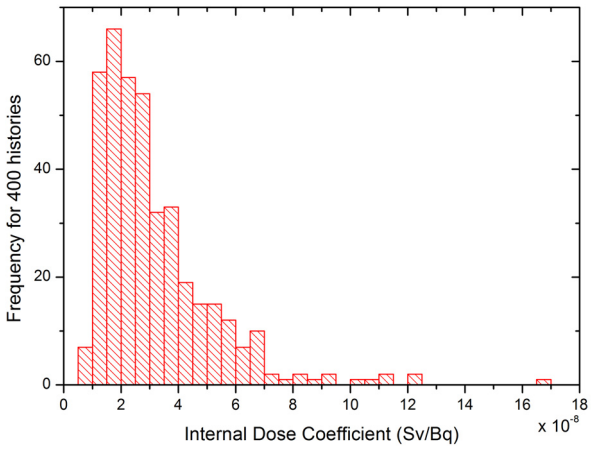

Fig. 2. The distribution of the internal dose coefficient for inhalation of ^{90}Sr.

Table III: Percentile values of the internal dose coefficient for inhalation of ^{90}Sr.

Percentile	5th	50th (median)	95th
Value (Sv/Bq)	1.094×10^{-8}	2.640×10^{-8}	7.148×10^{-8}

3. Conclusions

In this study, we developed the calculation module for uncertainty of the internal dose coefficient. In this module, uncertainty of various factor used to calculate the internal dose coefficient can be considered using the

Monte Carlo sampling method. After developing the module, we calculated the internal dose coefficient for inhalation of ^{90}Sr with the uncertainty and obtained the distribution and percentile values.

It is expected that this study will contribute greatly to the uncertainty research on internal dosimetry. In the future, we will update the module to consider more uncertainties.

ACKNOWLEDGEMENT

This work was supported by the Research Program for Development of the Radiation Safety Technology of Nuclear Safety and Security Commission.

REFERENCES

[1] CERRIE. Report of the Committee Examining Radiation Risks of Interal Emitters, Health Protection Agency CRCE, 2004.
[2] Birchall, and A. C. James, A Microcomputer Algorithm for Solving First-Order Compartmental Models Involving Recycling, Health Physics, Vol. 56, No.6, pp.857-868, 1989.
[3] International Commission on Radiological Protection, ICRP Publication 66: Human Respiratory Tract Model for Radiological Protection, Pegamon Press, 1994
[4] M. R. Bailey and M. Puncher, Uncertainty Analysis of the ICRP Human Respiratory Tract Model applied to Interpretation of Bioassay Data for Depleted Uranium, HPA-RPD-023, 2007.
[5] M. Puncher, Assessing the Reliability of Dose Coefficients for Ingestion and Inhalation of ^{226}Ra and ^{90}Sr by Members of the Public, Radiation Protection Dosimetry, Vol.158(1), p.8-21, 2014.
[6] International Commission on Radiological Protection, ICRP Publication 100: Human Alimentary Tract Model for Radiological Protection, Pegamon Press, 2006.
[7] International Commission on Radiological Protection, ICRP Publication 30: Limits for Intakes of Radionuclides by Workers, Part 1, Pegamon Press, 1979
[8] National Council on Radiation Protection & Measurements, NCRP Report No.164: Uncertainties in Internal Radiation Dose Assessment, 2009.
[9] International Commission on Radiological Protection, ICRP Publication 67: Age-dependent Doses to Members of the Public from Intake of Radionuclides - Part 2 Ingestion Dose Coefficients, Pegamon Press, 1992.
[10] A. I. Apostoaei and L. F. Miller, Uncertainties in Dose Coefficients from Ingestion of ^{131}I, ^{137}Cs, and ^{90}Sr, Health Physics, Vol.86(5), p.460-482, 2004.